State of the Art in Optical-Based Sensing

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The rapid expansion and advancement of the modern telecommunications industry has led to dramatic cost reduction in fiber optic components over the last few years. Light sources and source controllers, couplers, connectors, wavelength demultiplexers, and many other components have been utilized by the industry as important elements in the growth of communications capabilities. One of the most exploited fiber optic technologies has been the fiber Bragg grating (FBG), which is a simple in-fiber element that may be photowritten into silica fiber. In addition to the well-known advantages of fiber optic sensing such as electromagnetic noise immunity, electrically passive operation, low weight penalty, and high sensitivity, gratings are inherently “localized” sensors (much like conventional strain gages), allowing construction of extensive multiplexible arrays that may be used in distributed sensing applications. The literature has provided many examples of the use of Bragg gratings as sensors for a variety of measurands, and two collections of works demonstrating their use in specifically civil structure and health monitoring applications may be found in [1-2].

Gratings are written through holography or phase mask techniques by impinging periodically-spaced ultraviolet radiation over a small (typically, 1 cm) length of the fiber core. Electronic absorption in the ultraviolet range induces a permanent periodic modulation (i.e., a “grating”) of spatial period T in the local refractive index of the fiber core. If light is then inserted down the fiber as a guided mode, the modulated refractive index causes the grating to behave like a narrow-band wavelength filter, with all but a small wavelength light band able to pass through the grating structure (also shown in the left-hand picture of Figure 1). The center wavelength (with reflection bandwidths on the order of 0.1-0.2 nm) of this non-transmitted (reflected) light λ_r is proportional to the spatial period T. Thus, any physical effect in the fiber (such as strain or temperature) that changes T changes the reflection wavelength. Since each FBG may be manufactured to reflect at a unique wavelength, wavelength-domain multiplexing of multiple FBGs on a single fiber is feasible. Typically, these reflection wavelengths are

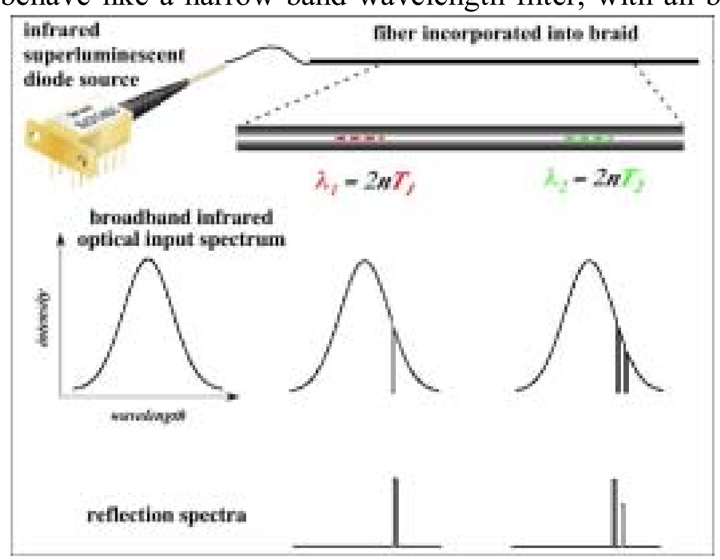

Figure 1. Wavelength-addressed FBG multiplexing.

designed to be in the far infrared region (1550 nm), where broad-band light sources are readily available.

Given this operational mechanism, the principal requirement for developing a grating-based measurement system, regardless of what specific measurands the gratings are designed to measure, is to track the various grating wavelength reflection shifts. A number of approaches have been proposed, but most of them may be broadly classed into conventional wavelength-division demultiplexers (WDMs), scanning Fabry-Perot (SFP) filter interrogation, tunable acousto-optic filter interrogation, and prism/CCD-array techniques. More recently, a new hybrid technique has been demonstrated that retains certain advantages from some of the earlier methods while improving overall performance [3]. In almost all metrics, optical-based systems outperform conventional resistive gages. Of particular note are the resolution improvement (up to four orders of magnitude) and significantly enhanced multiplexing capability. Fiber gages can be multiplexed in to a single optical fiber requiring very low telemetry cost. Depending upon the application dynamic range requirements, up to 20 or so Bragg gratings may be interrogated by a single optical channel.

This work will conclude by demonstrating the deployment of a fiber optic strain measurement system on an interstate bridge (I-10) in Las Cruces, New Mexico. The bridge is multi-span, and each span consists of a concrete deck supported by welded steel plate girders with an I-beam geometry. The instrumented span is approximately 36 meters long between concrete piers, and each edge of this span is supported by rollers. Sensors were attached along the lengths of all seven girders at various span locations, and 78 FBG sensors were interrogated simultaneously during a 9-month period while the bridge was in regular service. Significant amounts of data regarding traffic monitoring, real-time girder deflection estimates, weigh-in motion, and possible health monitoring were obtained, and key results will be reported.

References:

[1] Ansari, F. (ed.), (1998), Fiber Optic Sensors for Construction Materials and Bridges, Technomic, Lancaster, PA

[2] Chang, F. K. (ed.), (2001), Structural Health Monitoring: Demands and Challenges, CRC Press, Boca Raton, FL

[3] Todd, M. D., Johnson, G. A., and Althouse, B. L., (2001), "A Novel Bragg Grating Sensor Interrogation System Utilizing a Scanning Filter, a Mach-Zehnder Interferometer, and a 3x3 Coupler," Measurement Science and Technology, v. 12, n. 7, pp. 771-777.

Keywords:

Fiber Bragg grating: In-fiber refraction modulation that serves as an optical notch filter.

Scanning Fabry-Perot (SFP) filter: A tunable device with two mirrors that may be adjusted to allow passage of narrowband optical wavelengths.

Interferometry: Interference of optical signals; in this context, it is used to convert wavelength to optical phase difference.